



When Will We Detect GWs? (sooner than you think*)

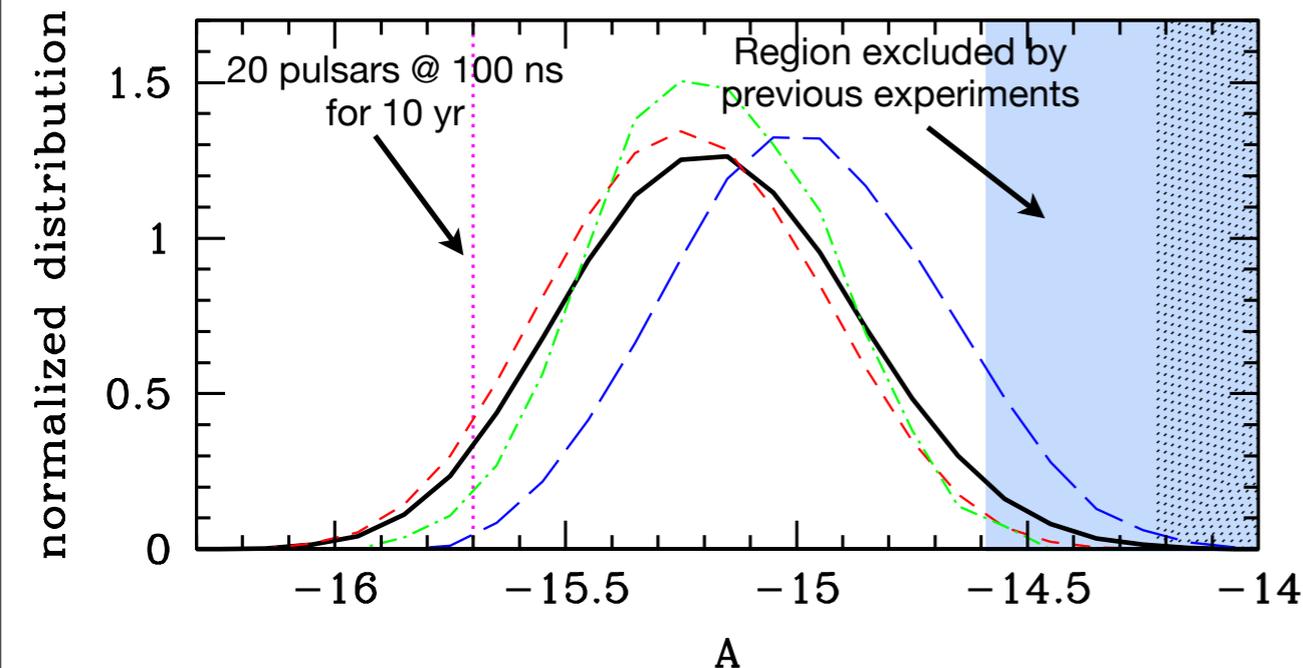
Justin Ellis and Xavier Siemens

Physical Applications of Millisecond Pulsars
Aspen, CO
January 23, 2013

*probably

Expected level of SMHB Stochastic Background

Sesana et al, 2012 (arXiv:1211.5375)

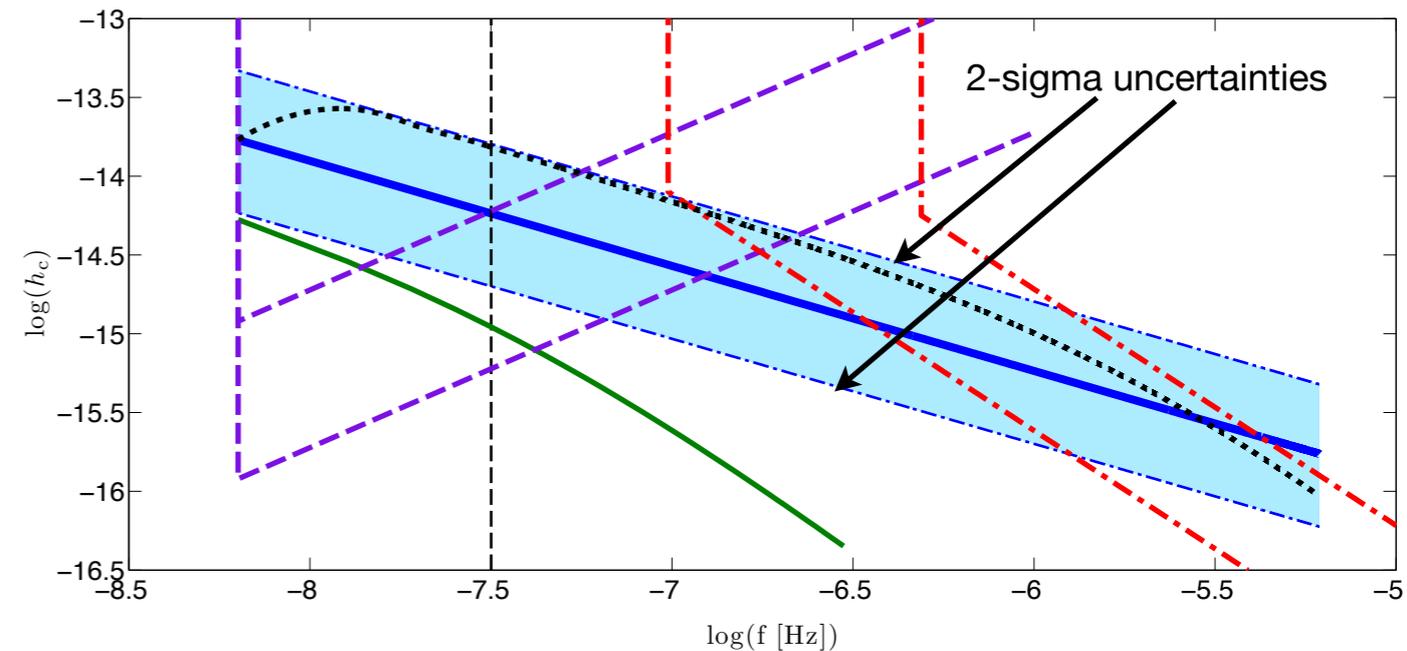


1-sigma bounds on amplitude are

$$5.6 \times 10^{-16} < A < 2 \times 10^{-15}$$

with a mean of $\langle A \rangle = 1 \times 10^{-15}$

McWilliams et al, 2012 (arXiv:1211.5377)



Places 2-sigma lower limit on the expected amplitude of $A > 2 \times 10^{-15}$ with mean

$$\langle A \rangle = 5.8 \times 10^{-15}$$

Bottom Line: Predictions of the SMBHB stochastic background amplitude based on observations and more reliable models are larger than previously thought.

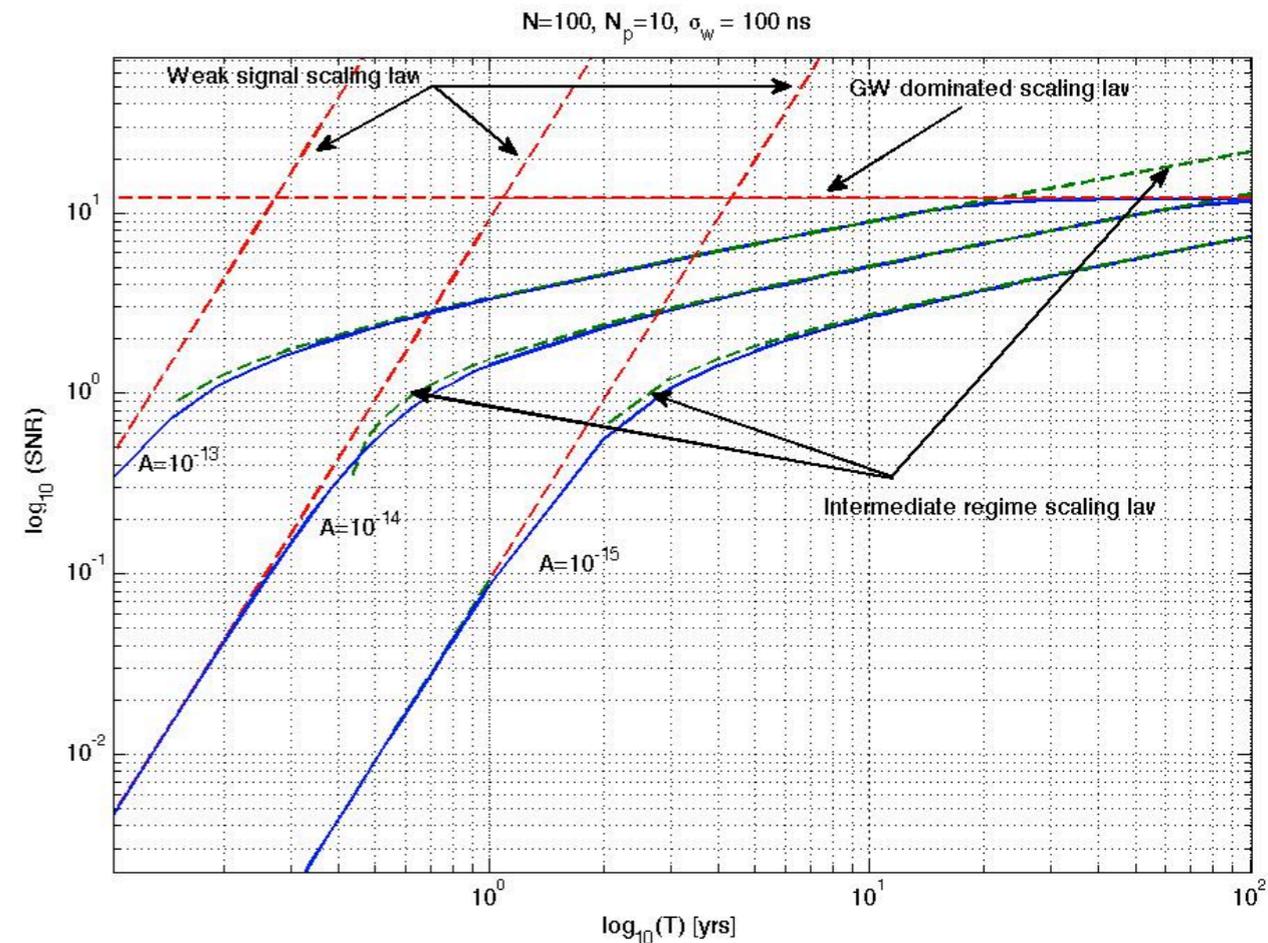
Optimal Statistic Scaling Laws

- Optimal pairwise cross correlation statistic.
- We are interested in the signal to noise ratio of the cross correlations.
- Very stringent test for stochastic GWB because it only focuses on cross correlations and not on the auto-correlations that will contain uncorrelated noise.

General Scaling Laws:

Weak Signal Limit: $\langle \rho \rangle \propto N_p \mathcal{C} \left(\frac{A}{\sigma} \right)^2 T^{4.33}$

Intermediate Regime: $\langle \rho \rangle \propto N_p \mathcal{C}^{0.12} \left(\frac{A}{\sigma} \right)^{0.23} T^{0.5}$



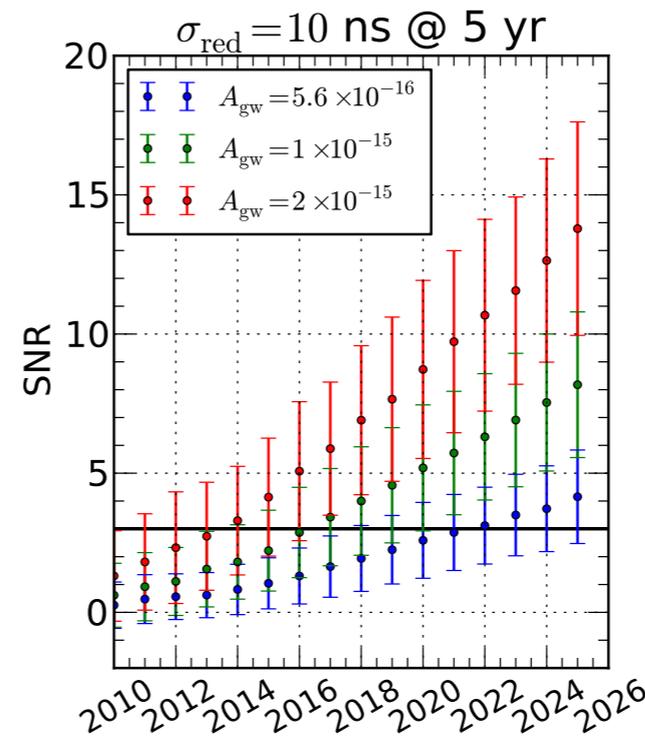
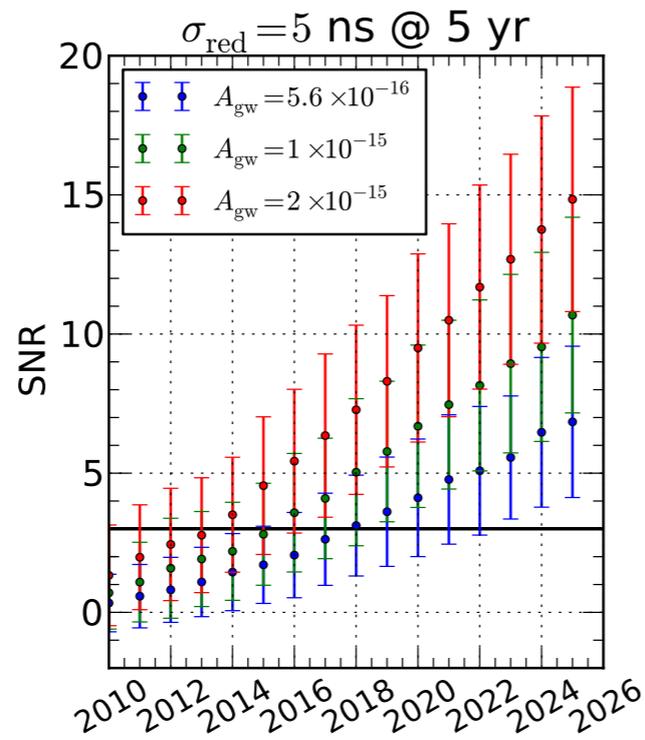
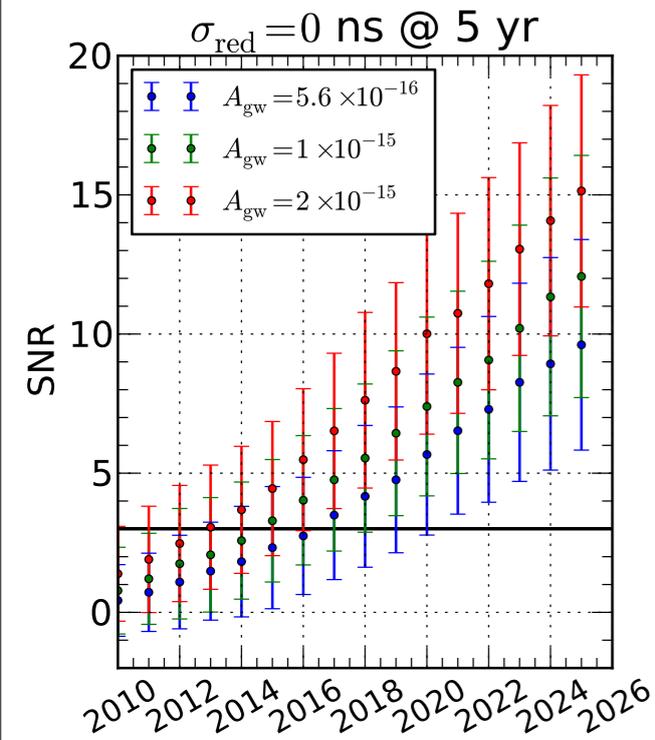
A : Strain Amplitude
 σ : White Noise RMS
 N_p : Number of Pulsars
 \mathcal{C} : Cadence (TOAs per year)
 T : Observing Time

Bottom Line: In intermediate regime, the total number of pulsars and observing time dominates over the cadence and timing precision

Simulations

- Simulate data with 20 points per year, with varying levels of red and white noise and GWB amplitudes.
- Run 1000 injections for each year and use full optimal statistic (not scaling law) to compute the SNR.
- Caveats:
 - Only consider NANOGrav data (5 years of data in 2010)
 - Simple model that only uses quadratic subtraction
 - Use same intrinsic red noise in all pulsars

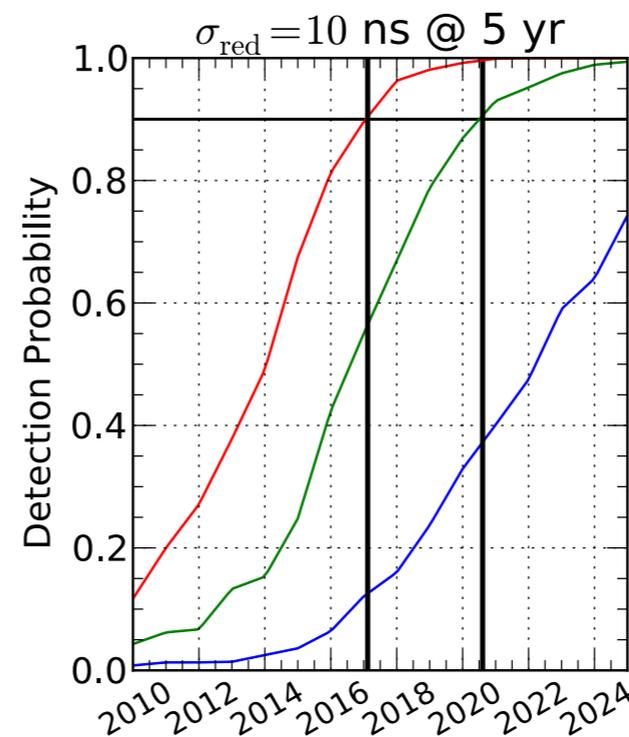
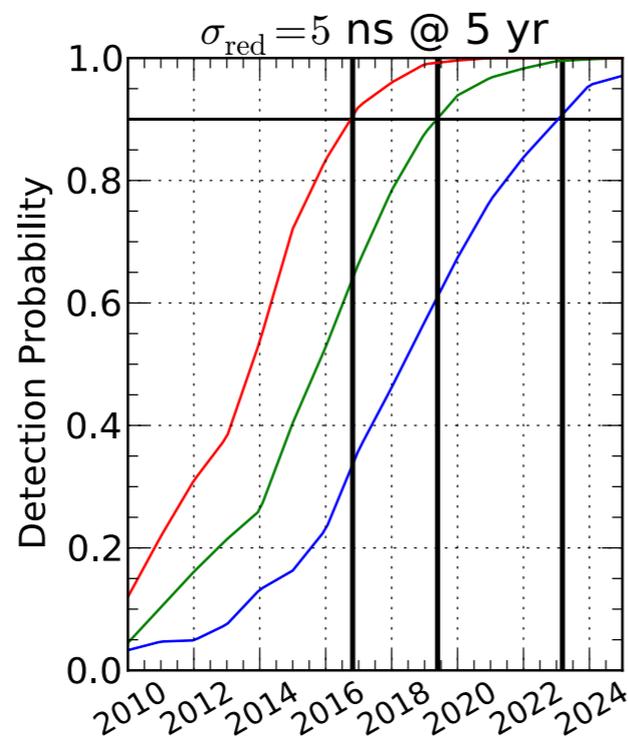
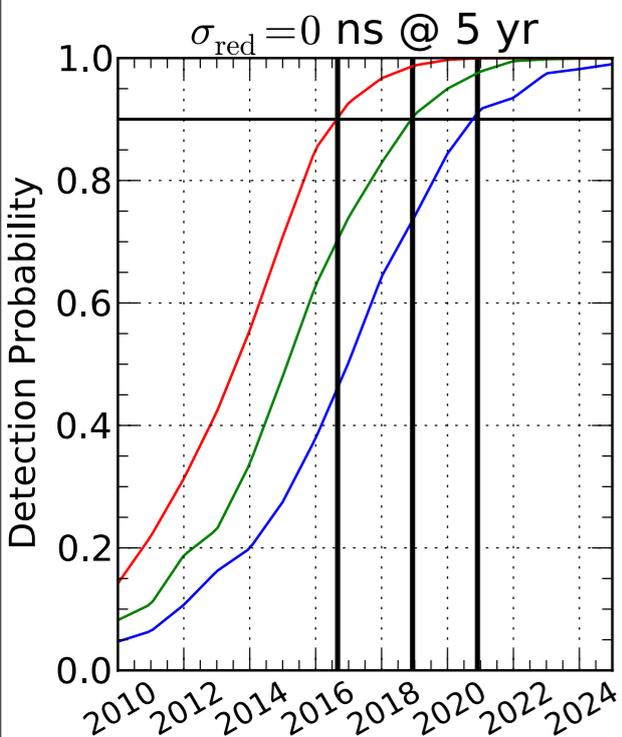
Status Quo (for NANOGrav)



17 pulsars with measured RMS @ 5 yr in 2010 and factor of 2 improvement thereafter due to hardware upgrades.

18 new pulsars added by 2012 with 200 ns RMS. (35 total)

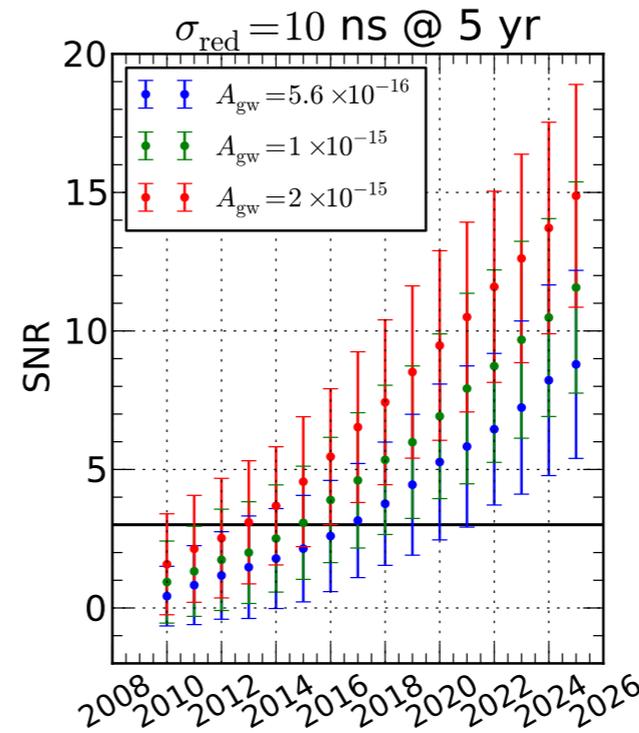
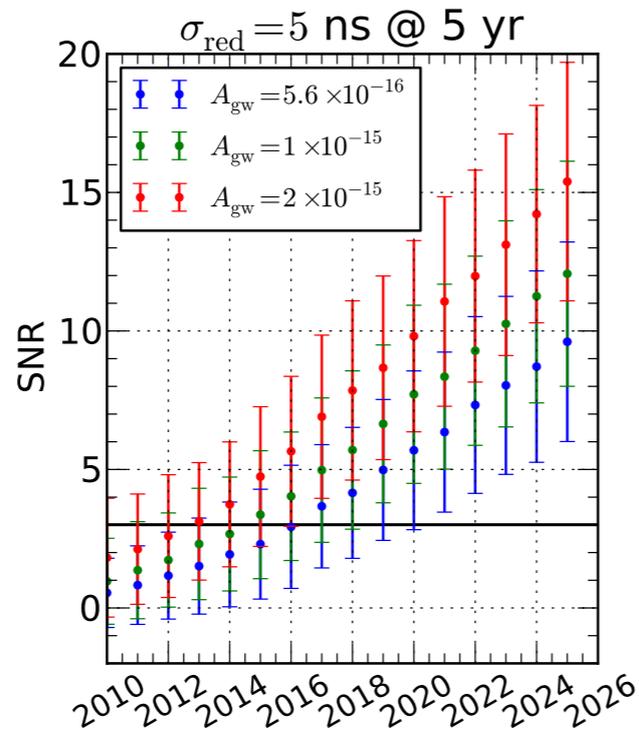
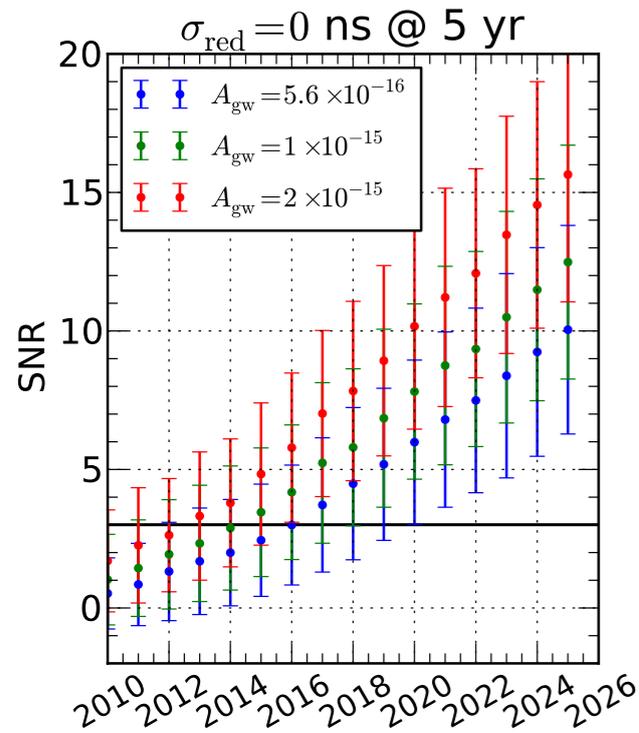
3 new pulsars per year after 2012 with 100 ns RMS. (71 pulsars by 2025)



Same cadence of 20 TOAs per year.

Very likely to make a detection in the next 10 years and possibly in the next 4 years!

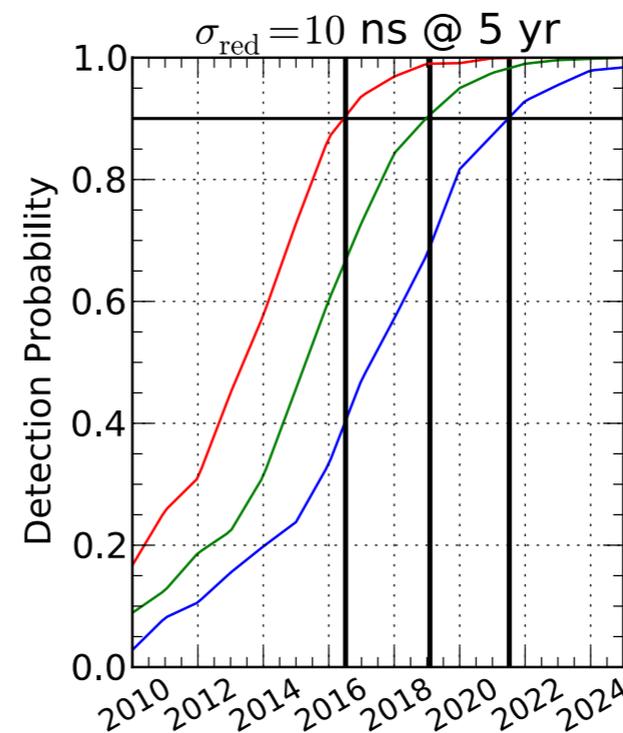
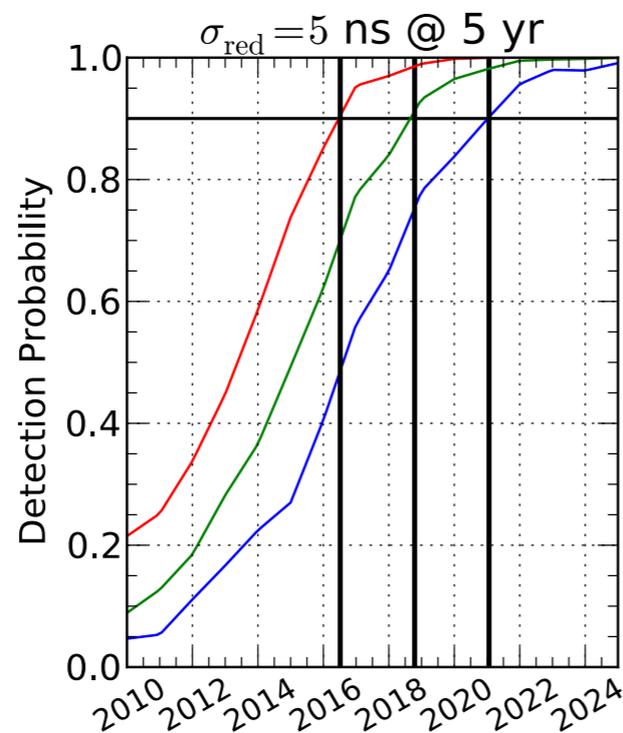
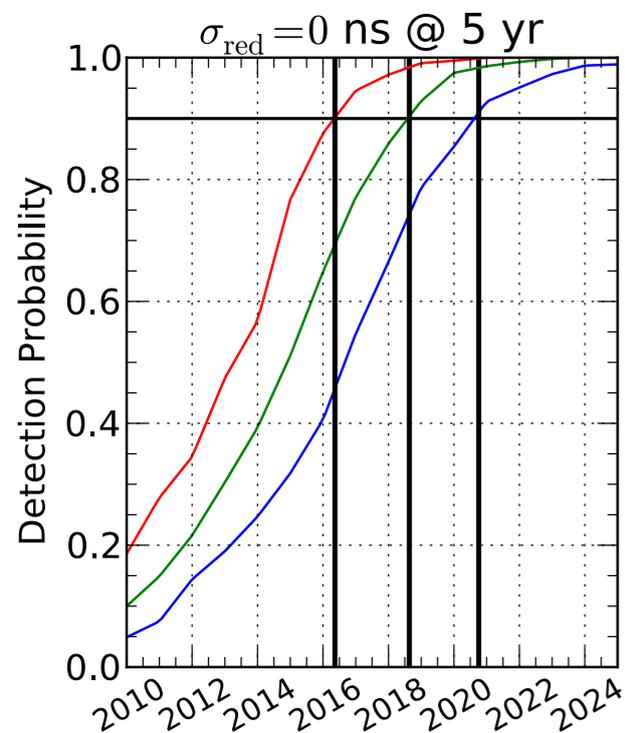
Status Quo (more data driven noise model)



17 pulsars with measured RMS @ 5 yr in 2010 and factor of 2 improvement thereafter due to hardware upgrades.

18 new pulsars added by 2012 with 200 ns RMS. (35 total)

3 new pulsars per year after 2012 with 100 ns RMS. (71 pulsars by 2025)

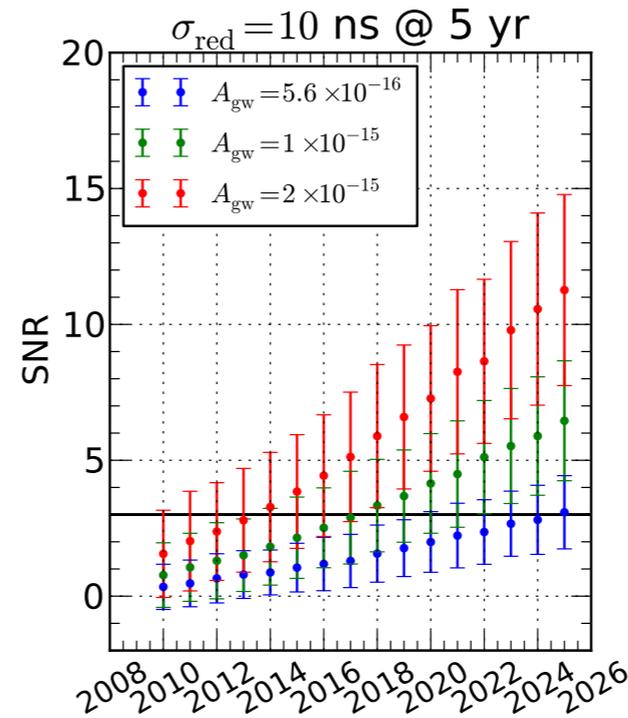
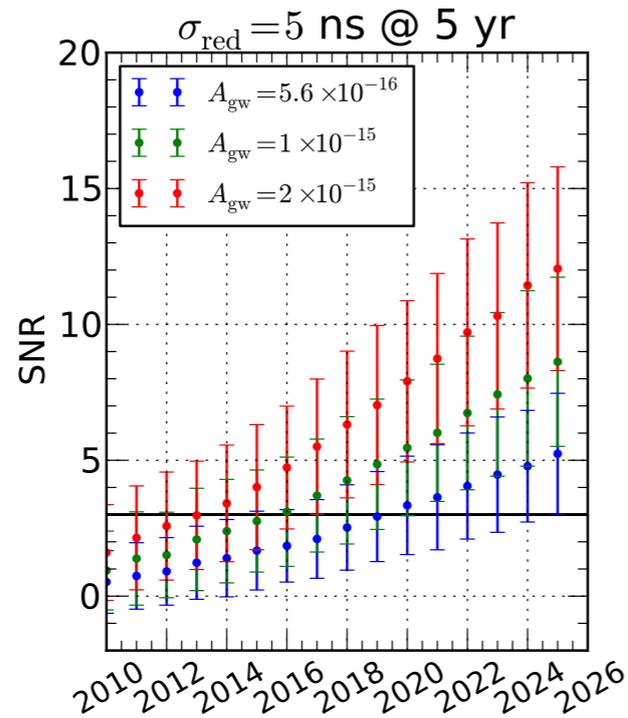
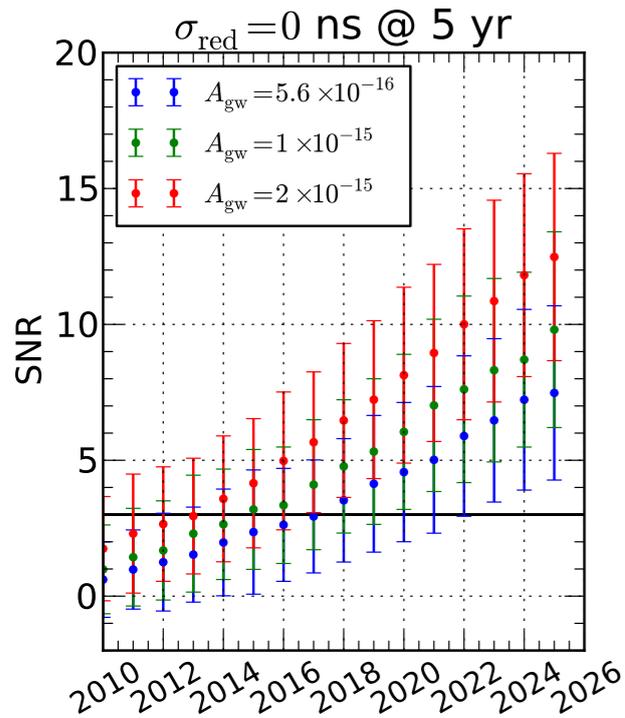


Same cadence of 20 TOAs per year.

Red noise with spectral index of 2.0 to conform to existing data sets.

Red noise has very little effect. Very likely to make a detection in the next 10 years and possibly in the next 4 years!

Adding Pulsars with Less Timing Precision



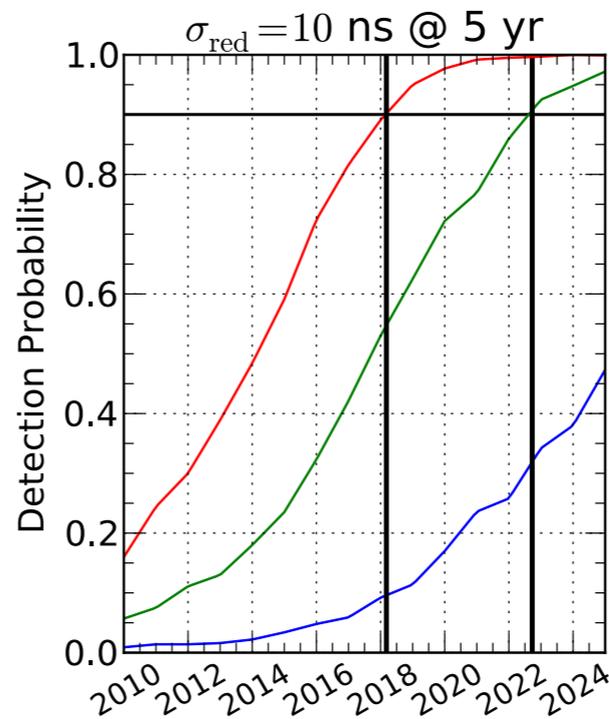
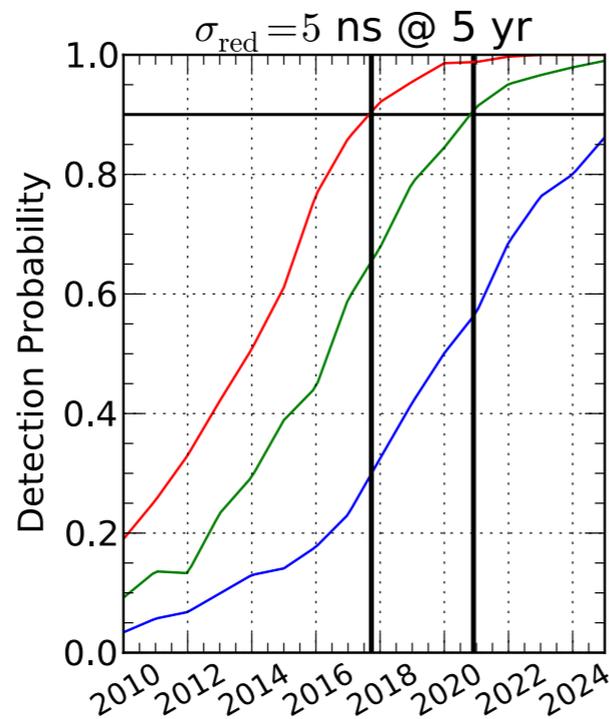
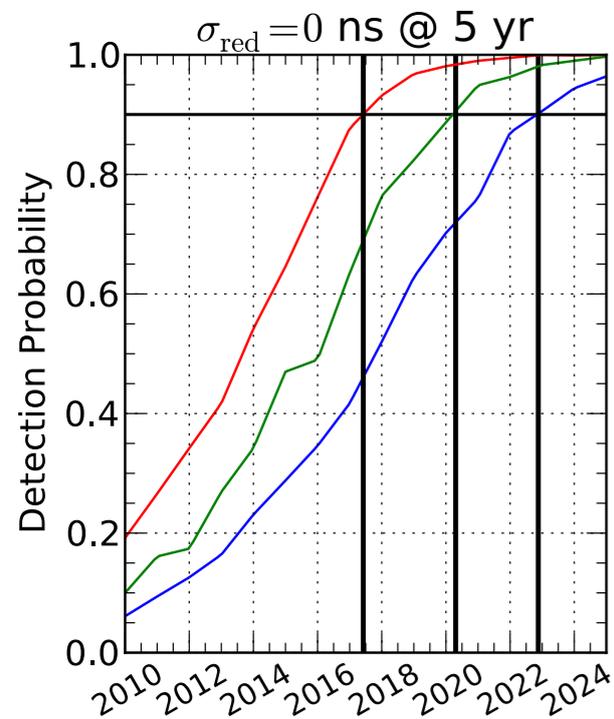
17 pulsars with measured RMS @ 5 yr in 2010 and factor of 2 improvement thereafter due to hardware upgrades.

18 new pulsars added by 2012 with 500 ns RMS. (35 total)

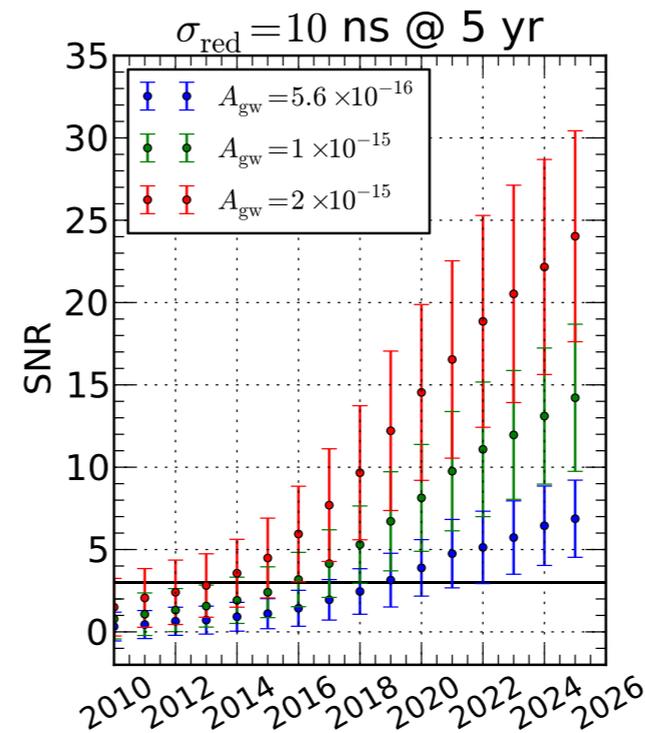
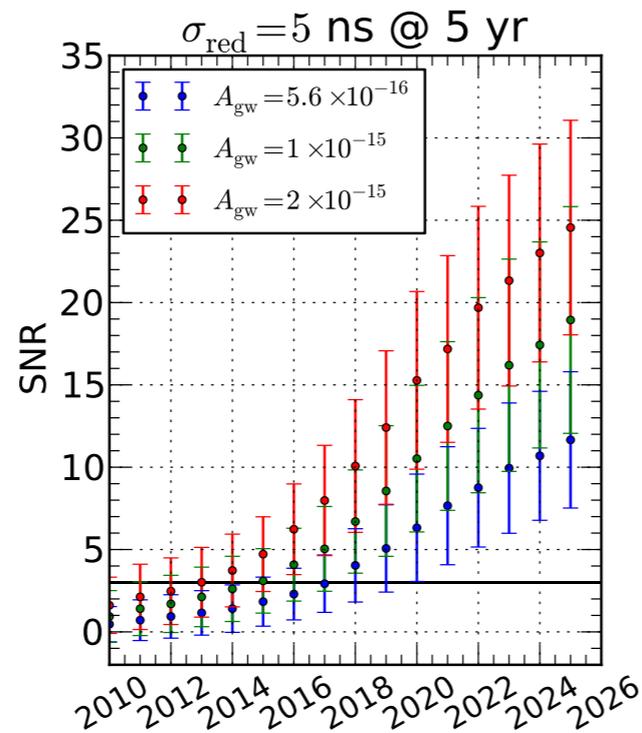
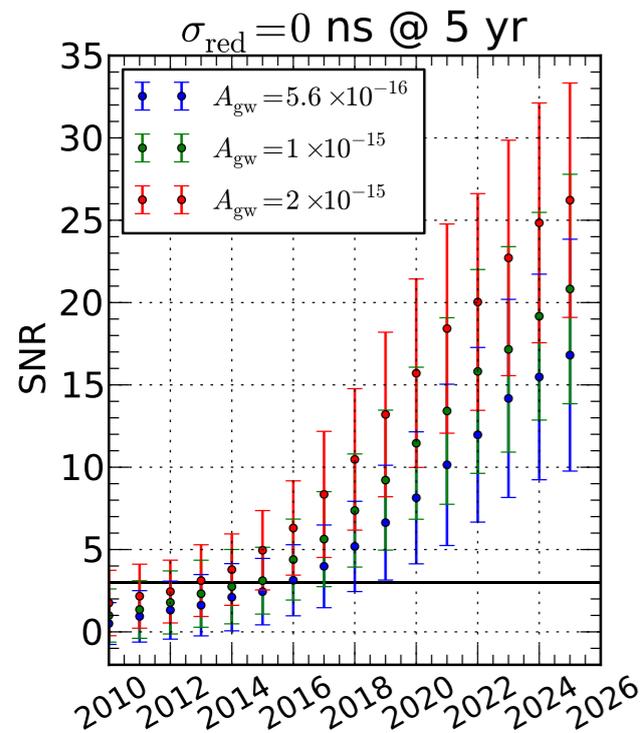
3 new pulsars per year after 2012 with 250 ns RMS. (71 pulsars by 2025)

Same cadence of 20 TOAs per year.

Still obtain similar results to the 100 ns case. Do not see a factor of ~6 difference (what we would expect from weak signal limit)



Aggressive Search and Timing Plan



17 pulsars with measured RMS @ 5 yr in 2010 and factor of 2 improvement thereafter due to hardware upgrades.

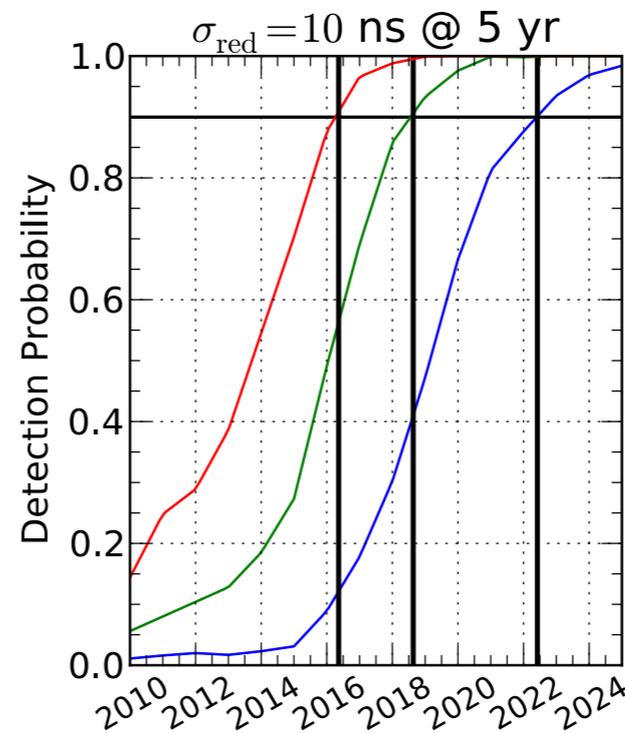
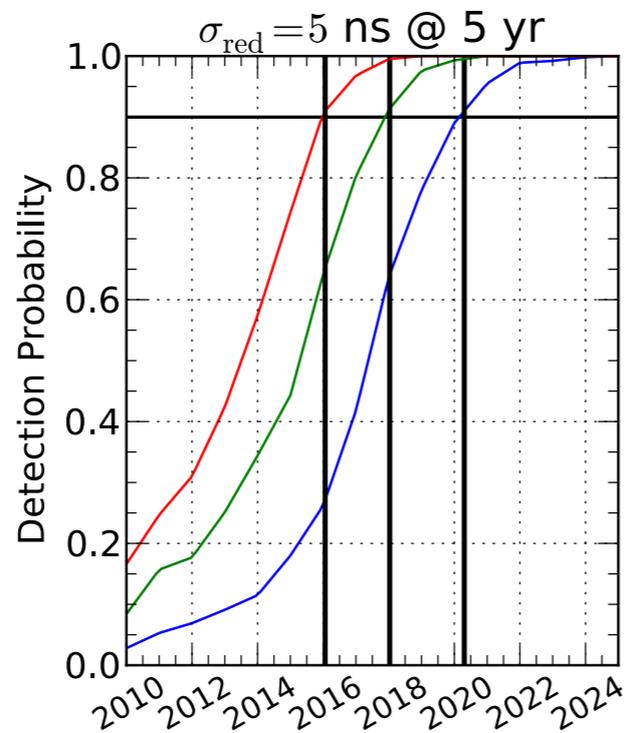
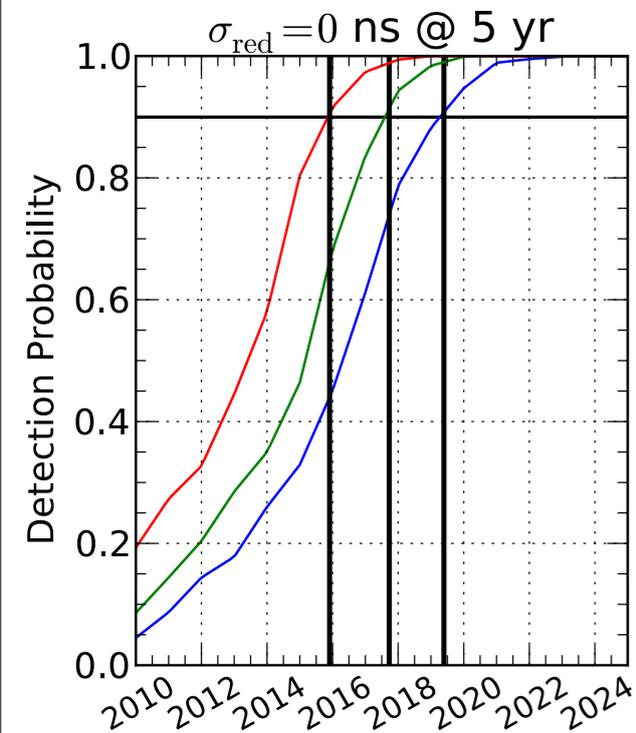
18 new pulsars added by 2012 with 200 ns RMS. (35 total)

13 new pulsars per year after 2012 with 100 ns RMS.

Time 100 pulsars by 2017 and dedicate all telescope time to timing. (Fixed 100 pulsars from 2017 onwards)

Same cadence of 20 TOAs per year.

Detect full range of possible amplitudes by ~2023. First detection by 2016 in best case scenario!

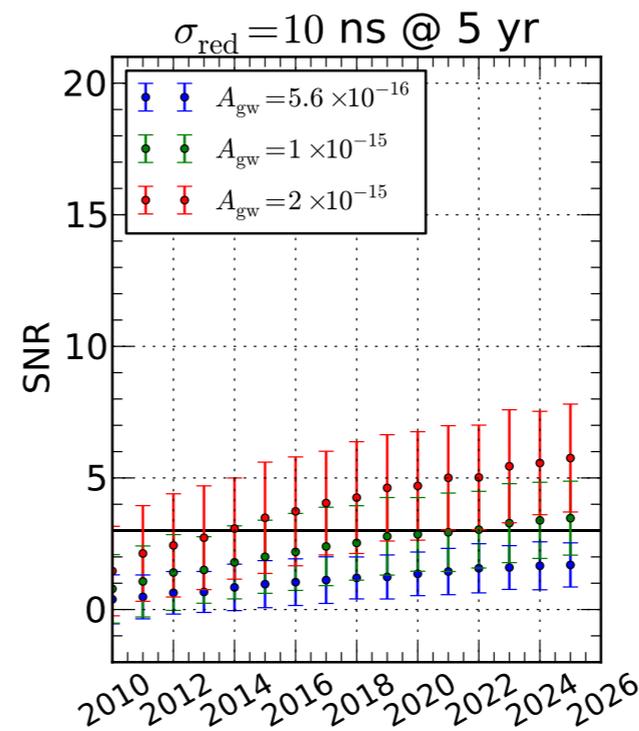
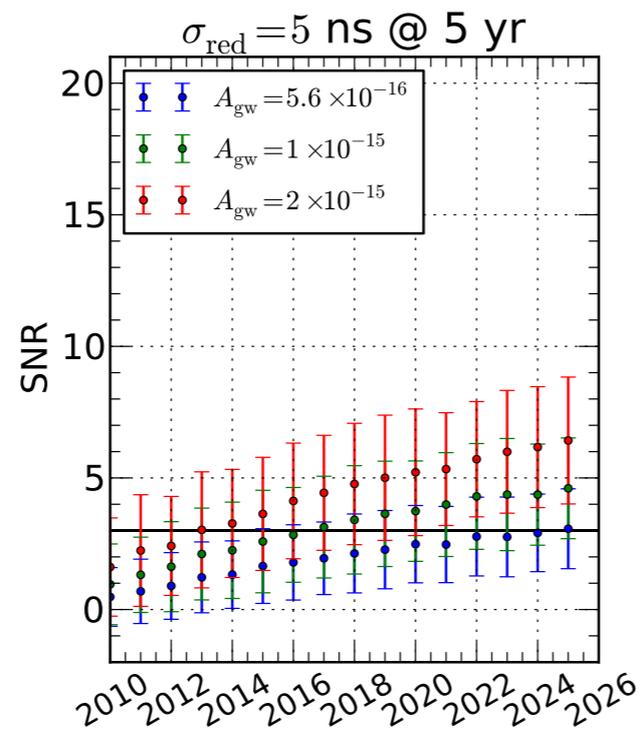
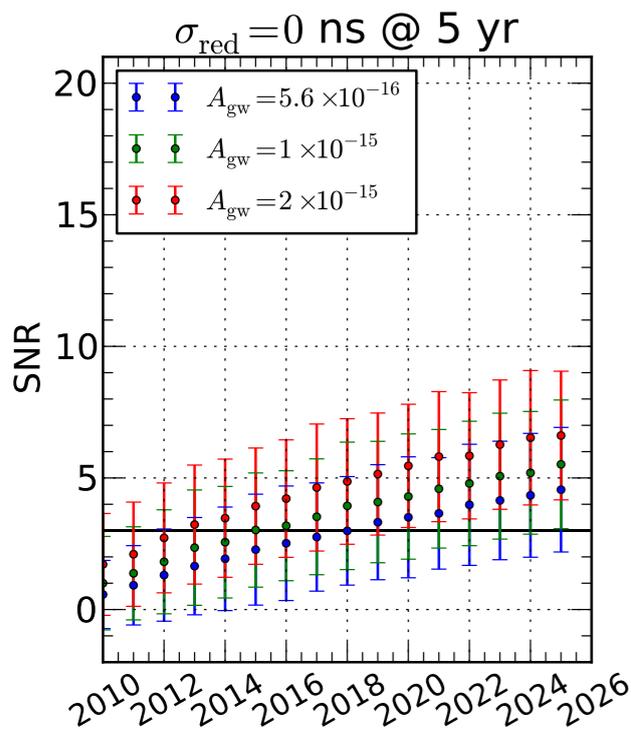


Summary

- Traditional scaling laws for SNR or detection significance are not valid in the signal regime (where we will actually make a detection).
- We approach this regime sooner than previously thought (we are already there!)
- High timing precision is great but it is most definitely not necessary or sufficient.
- Need more pulsars (not necessarily great timers)
- Long time baselines are crucial. First detection is likely to come from combined effort of IPTA.

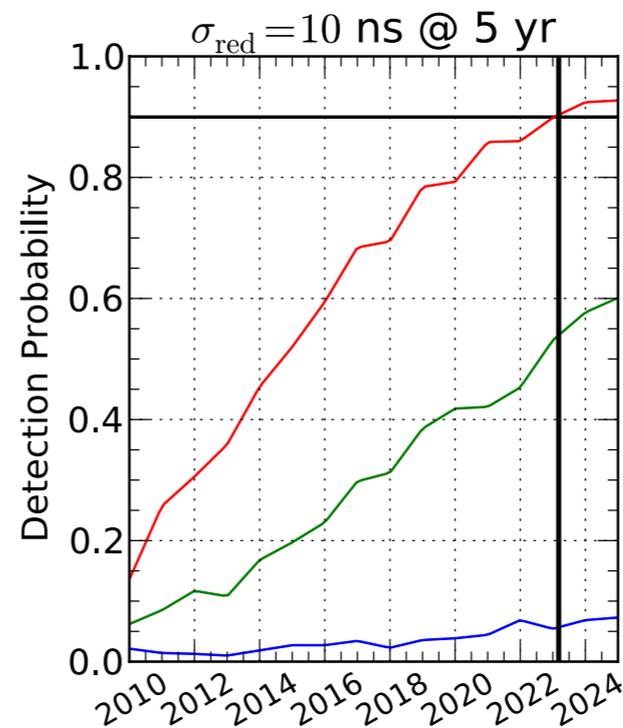
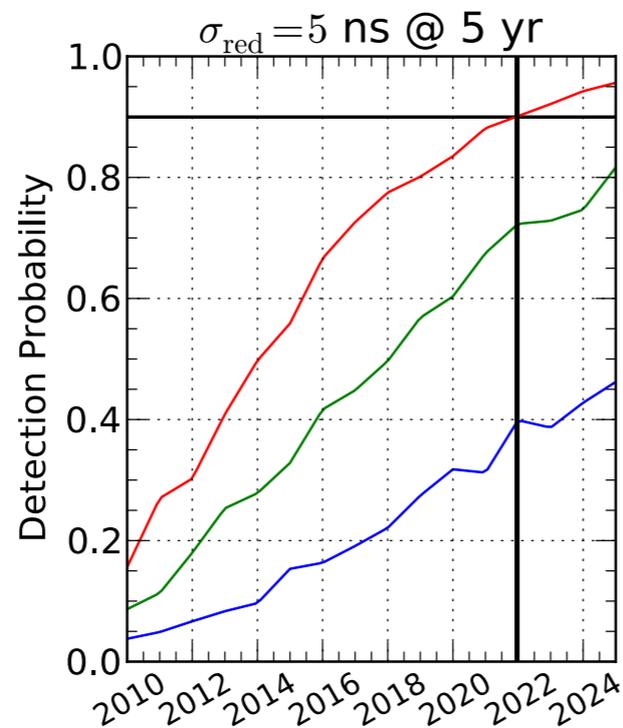
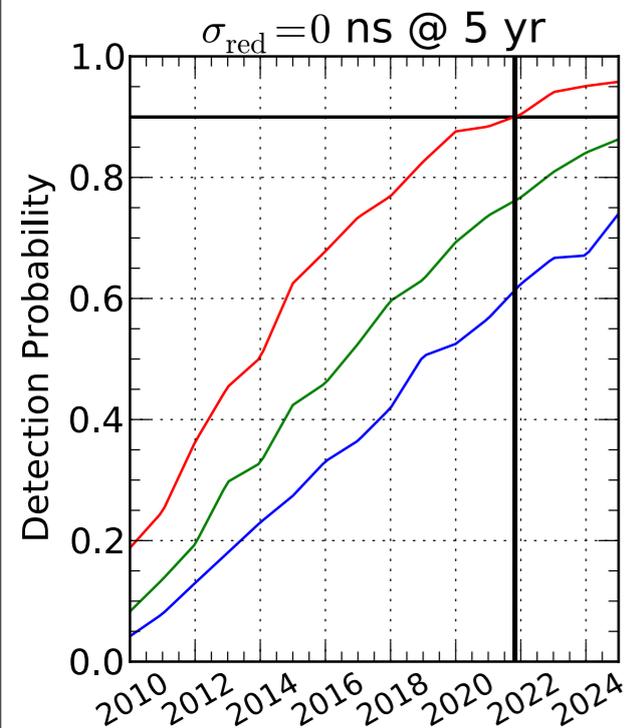
Extra Slides

Timing only 17 pulsars (no more searching)



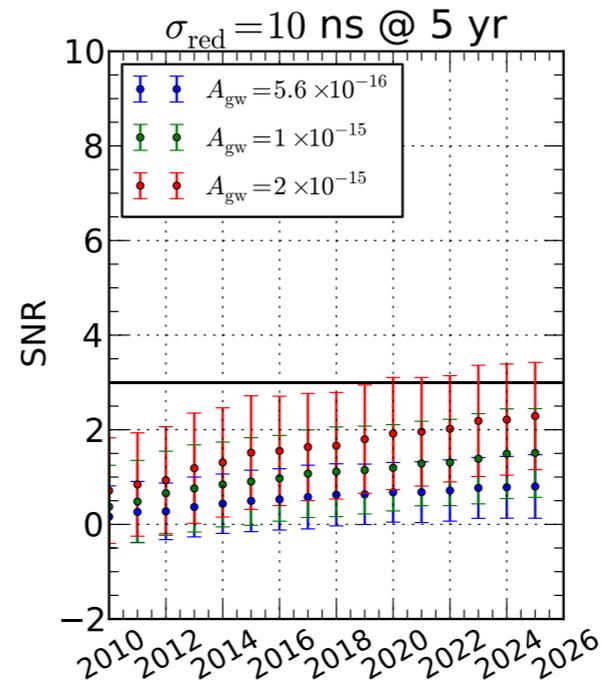
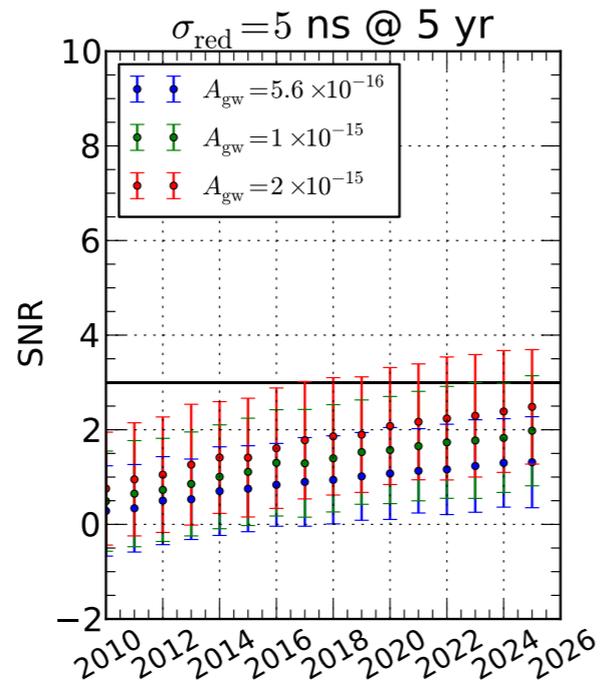
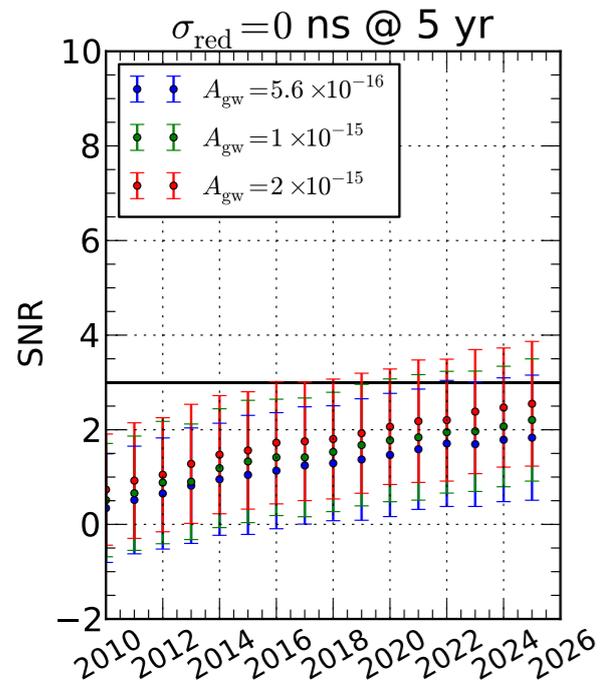
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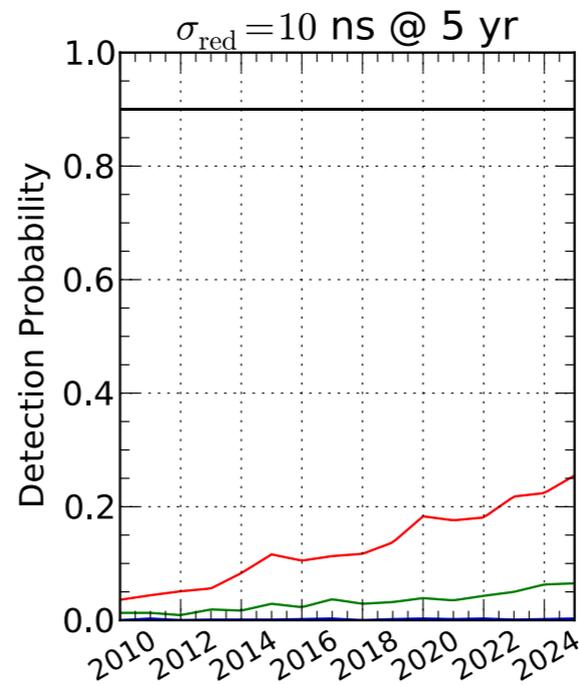
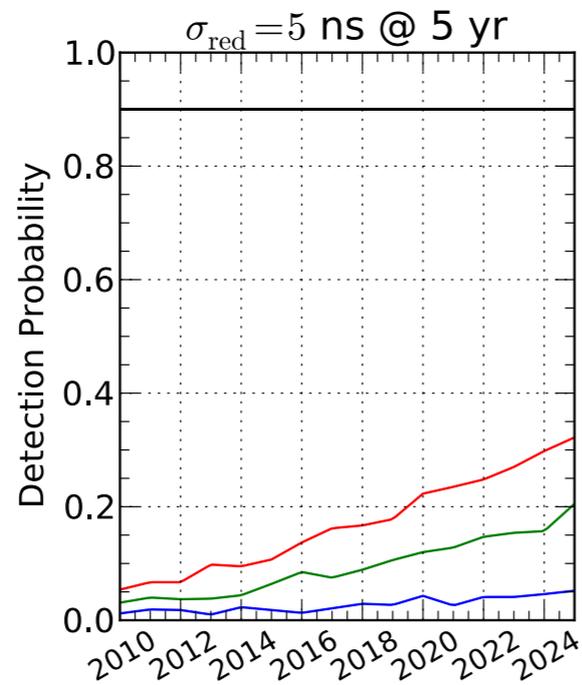
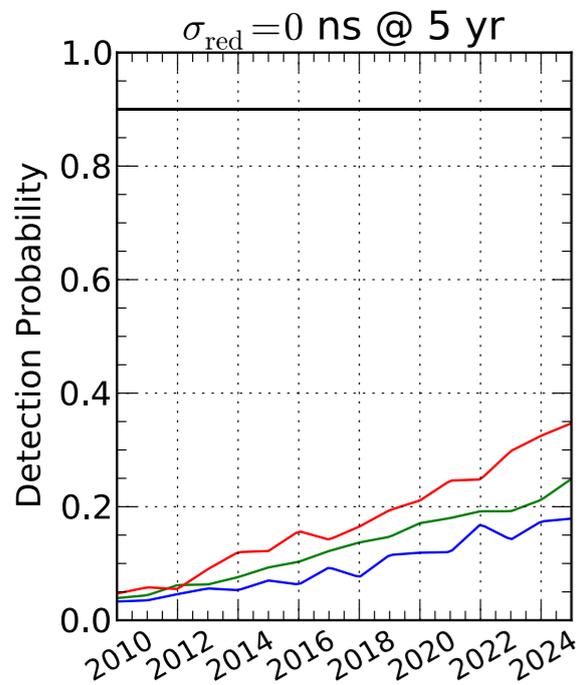
Only make detection of most optimistic signal within next ~10 years!

Only Timing the Best Pulsars



6 Best NANOGrav pulsars with 10 ns rms.

Same cadence of 20 TOAs per year.



Career change! (or bank on continuous sources)